Deposition of Nitrogenous Pollutants in the Chesapeake Bay Watershed

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State Advisory Board on Air Pollution

Subcommittee Members

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I. Current Information

A. Monitoring Sites and Data

Over the past twenty years, there have been many atmospheric deposition monitoring programs conducted by various governmental and non-governmental agencies to quantify air pollution impacts on the Chesapeake Bay watershed and link them with upwind sources. Most of the programs measure deposition of acid components ("acid rain"). The consensus opinion is that there are quantifiable links between air emissions and watershed effects. Many factors determine the downwind fate of air pollutants: chemical form of the air pollutant, detailed atmospheric conditions, nature of the emission sources, source elevations and chemical interactions with other compounds in the air mix. Each of these items can confound accurate representations of the airshed's effects within the boundaries of the Chesapeake Bay system.

A brief examination of the monitoring site locations and data availability indicates that the Bay Program participants, public and private, are considered at the leading edge of addressing relationships among air, water and land sources of nitrogen effects to the Bay. Several complex computer models have been developed and are extensively used to estimate the airborne nitrogen deposition to the Bay. The models use complex air transport calculations, understood by the researchers from the Chesapeake Bay Program, that are not easily comprehended by the policy makers and resource managers that determine the method and timing of pollution control strategy.

The many programs that have been established to measure wet and dry air deposition have obtained a large quantity of data that can be accessed. The most established monitoring sites are operated by the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). The NADP/NTN collects weekly samples to determine long term trends and geographic patterns of wet deposition. Historically, their sites have been located in rural areas to assess regional deposition patterns. However, urban point source effects and major transportation effects around the Chesapeake Bay, have not been adequately assessed. To improve on the NADP coverage, NOAA created the Atmospheric Integrated Research Monitoring Network (AIMoN) to monitor urban and coastal areas. The Monitoring Subcommittee of the Chesapeake Bay Program funded the Coordinated Atmospheric Deposition Monitoring (CADM) project in 1995. The task at hand was to compile and document existing atmospheric deposition data, where it is located, how it is stored and to enhance progress towards the development of an air deposition data base. The group discovered that most air monitoring data are not readily available to researchers as well as the general public.

Efforts of public, private and governmental sectors have pushed the evolution of deposition monitoring towards the collection of historical and present-day data into one web-based site. The Maryland Department of Natural Resources (MDNR) funded the creation of a deposition data website that is administered by Versar, Inc. Each operating network has a listing of measurements, QA procedures, site locations and a hyperlink to the data. The website will hotlink to the seven regional deposition monitoring programs and three national efforts that provide Precipitation Chemistry Data and information for non-technical users.

There have been several technical meetings partially funded by the VA DEQ in the last two years in which reviews of the available assessments of the databases have been provided. The one conclusion coming from most of the technical review is that more, technically improved deposition monitoring stations are needed to quantify the effects of respective oxidized and reduced nitrogenous effects from the air to the Chesapeake Bay Watershed.

B. Available Information / Studies / Models- RADM, NOAA, VADEQ, etc.

The best starting point for understanding the transport, deposition, and significance of key nitrogenous pollutants (ammonia, NH_3; reactive nitrogen oxides, NO_x; nitric acid, HNO_3; and inorganic nitrates, NO_3^-) in the Chesapeake Bay Watershed is to read the third Airsheds & Watersheds workshop report, known as the Dewey Beach workshop (Kerchner et al., Nov., 2000; available online and attached in this report). Additional detailed information can be found in the various references cited in the workshop report. The workshop was sponsored by, and included significant expertise from individuals associated with, the Chesapeake Bay Program, EPA Great waters program, the NOAA Air Resources Laboratory, and the Mid-Atlantic Regional Air Management Association. The workshop's objectives were "to generate an awareness of the impacts of ammonia emissions to our air, land, and water environments and to lay the foundation for understanding the primary emission sources, the magnitude of these emissions, and the atmospheric transport and fate of the nitrogen on a regional and local scale." Thus, although the workshop's focus was on airborne ammonia sources, it is a consequence of recent NO_x-reduction technology and atmospheric/terrestrial nitrogen chemistry that the report also contains important details on both NH_3 and NO_x emissions – i.e., from motor vehicles with modern catalytic converters, and stationary sources equipped with either Selective Catalytic Reduction (SCR) or Selective Non-Catalytic Reduction (SNCR) systems. In general, the report describes fundamental characteristics of the terrestrial nitrogen cycle, including transport and deposition of airborne species into various ecosystems, chemical processing including nitrification, denitrification, plant uptake, saturation and leaching processes, and finally the effects and fate of nitrogenous pollutants in the Bay itself.

With regard to the distribution of ammonia sources in Virginia, a recent SAB Subcommittee report on Ammonia Inventory Methodology (Pellett et al., Nov. 2001) independently developed detailed analyses that summarized past, present, and near-future statewide NH_3 inventories (but, without geographic information). The estimates were derived from very recent data on mobile sources, and projected SCR and SNCR sources. Projected overall ammonia emissions of 69,000 tons/yr in Virginia included a pie chart showing the following source distribution: 56.4% from farm animals (dairy and beef cattle, hogs and pigs, poultry, sheep and lambs, horses; 18.7% from mobile sources equipped with triple-catalytic mufflers (94 mg NH_3/km); 6.5% from fertilizer; 5.9% from industry (top 69 sources in Virginia 1998 TRI inventory); 5.1% from refrigeration; 4.4% from *assumed* high-efficiency SCRs (5 projected units operating during the 5 ozone-months); and 3.1% from Publicly Owned Treatment Works. This projected distribution shows a substantial increase in mobile source contribution that reduces the percent contribution from animals.

Some important information on the “nitrogen airsheds” and patterns of deposition of “reduced nitrogen” (e.g. NH_3) and “oxidized nitrogen” (e.g., NO_x, HNO_3, and nitrates) is given in the Dewey Beach Workshop report.

C. Future Models and Studies

CALPUFF is presently considered to be the best available tool for the accurate assessment of multisource pollutant transport. However, full implementation of the CALPUFF modeling method has not been targeted. VADEQ is a member of MARAMA, which is planning a comprehensive CALPUFF Initialization Project affecting all areas in the MARAMA region. The CALPUFF modeling system has been used in most Virginia PSD projects over the last two years either in a screening mode or in a domain based refined mode that depends upon the requirements of increments and air quality related values such as visibility, total nitrogen and total sulfur deposition. The MARAMA Initialization Initiative is still in the planning stages, and the endeavor has not been completely agreed upon by all States and Local management, it is envisioned that the CALPUFF model will be used over the entire MARAMA region. As a final noted, however, funding remains in question and may delay implementation and even change the looks of the overall project.

Summary of the Mobile 6 Model

Mobile source emissions models calculate emission factors for volatile organic compounds (VOCs), nitrogen oxides (NOx) and carbon monoxide (CO) from onroad vehicles such as passenger cars, sport-utility vehicles, motorcycles, buses, and heavy-duty trucks. The model incorporates parameters that change over time, such as vehicle emission standards, and also requires local or regional inputs that can affect emission rates such as temperature, humidity, fuel quality, registration data, and vehicle emission control programs. Mobile models are typically used to calculate current and future inventories of motor vehicle emissions that are used to make decisions about air pollution policies and programs at the local, state and national level. The mobile model is also used to calculate inventories required that meet certain federal Clean Air Act requirements, such as state implementation plans (SIPs) and transportation conformity analyses.

EPA officially released an update to the mobile source emissions model, called MOBILE6, on January 29, 2002. The release marked the first major revision to the mobile model since May 1994 when EPA originally released its predecessor, MOBILE5. Since MOBILE6 is based on new and improved emissions data compiled by EPA over the last decade, it can produce emissions estimates that differ significantly from previous versions of the model.

States are generally given a two year grace period before MOBILE6 is required for use in new State Implementation Plans (SIPs) and transportation conformity analyses. Although some areas are required to revise previously submitted SIPs in one or two years from MOBILE6’s release date based on previous commitments, most SIPs created with older versions of the mobile model are not required to be revised, including the Maintenance Plans for both Richmond and Hampton Roads. States may choose to update these plans anyway with MOBILE6 based on transportation conformity concerns. Northern Virginia's Attainment Demonstration was originally required to be revised using MOBILE6 by January 29, 2003, however this requirement vanished when the Attainment Demonstration was vacated by the DC Circuit Court in July 2002. It is likely that Northern Virginia will be required to submit a revised Attainment Demonstration to EPA by January 2004 that meets the requirements for a severe ozone nonattainment area using MOBILE6.

Total VOC and NOx emissions from the mobile source sector are currently declining in Virginia because the introduction of cleaner vehicles into the fleet are more than offsetting any projected growth in vehicle miles traveled. This trend is expected to continue until at least 2015-2020 since even more stringent gasoline and diesel vehicle standards are on the way. EPA's Tier II vehicle emissions and gasoline fuel regulation takes effect in 2004, as well as EPA's 2004 and 2007 diesel vehicle and fuel regulations.

NOAA and US EPA Modeling Effort

The U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) have done extensive modeling to predict the amount of nitrate nitrogen (NO_3-N) deposition to the Chesapeake Bay watershed from NO_x emissions in the eastern 36-state modeling domain. Nitrate deposition, from nitrogen oxide emissions, has been the focus of attention since emissions inventories for other nitrogen species (e.g., ammonia/ammonium ion, organic nitrogen) are incomplete and there are currently no regulatory emission control requirements for these emissions. An assumption that has been used in assessing the results from these modeling studies is that about 70-75% of the atmospheric deposition of total nitrogen is in the oxidized form (i.e., NO_3-N).

Modeling has been performed by the Atmospheric Modeling Division of EPA/NOAA, using the extended version of the Regional Acid Deposition Model (Extended-RADM) located in Research Triangle Park, NC. NO_x emissions from the 1990 inventory provided the input for these studies. These emissions were available for stationary area sources (e.g., residential, commercial, etc.), non-road area sources (e.g., construction equipment, lawn mowers, etc.), electric generating units (i.e., power plants), non-electric generating units (i.e., industrial point sources), and mobile sources.

The modeling study results estimate the relative impact of deposition to the Chesapeake Bay from various atmospheric sources. The results also provide further insight into the contribution from air emissions sources within Virginia, the Chesapeake Bay Basin states, the signatory states and states outside of the Basin.

D. Conclusion

There are several deposition monitoring programs available to assist in developing Agency policy. In fact, the data from most of the Chesapeake Bay programs can be considered leading edge examples of what is needed to estimate the airborne nitrogen input. Likewise, the complex computer models used by federal and state programs provide technologically advanced pictures of the Bay airshed. However, the models are not readily available for use and are not clearly understood by the numerous policy managers outside the technical arena of the Bay states air programs.

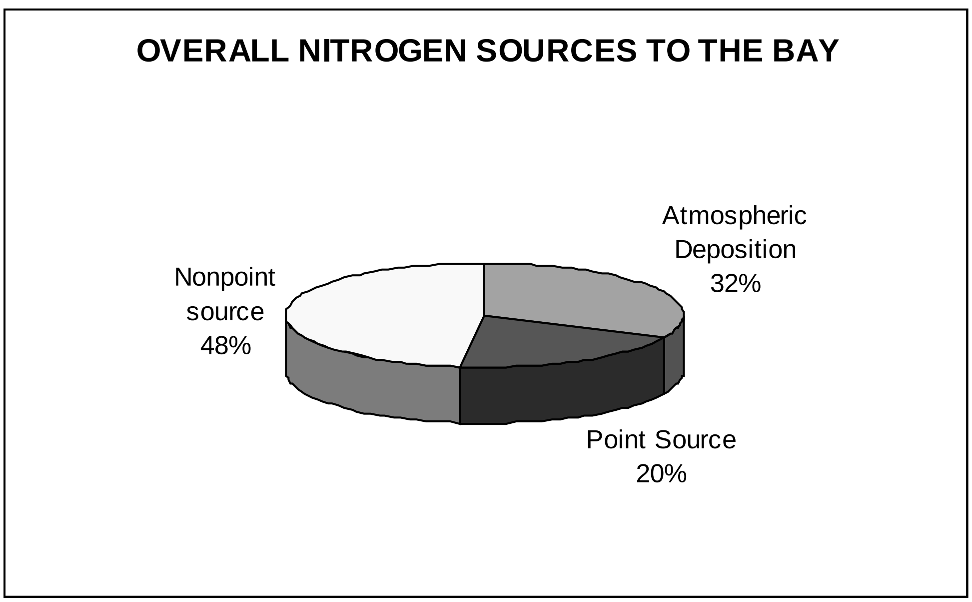
II. Contributing Sources and States

A. Basin States

The Basin States for the Chesapeake Bay Watershed are Delaware, Maryland, New York, Pennsylvania, Virginia and West Virginia. The Extended Regional Acid Deposition Model was used by NOAA to examine the relative contribution of the Basin states to the nitrogen loading of the Bay. The 1990 emission inventory used for the modeling exercise has a total NOx emission of 3,517,354 tons.

Results

Thirty two percent of the nitrogen loading of the Bay is calculated to come from atmospheric deposition. Sources in the airshed explain approximately 76% of the atmospheric deposition. The Basin states emissions contribute 49% to the airshed deposition.

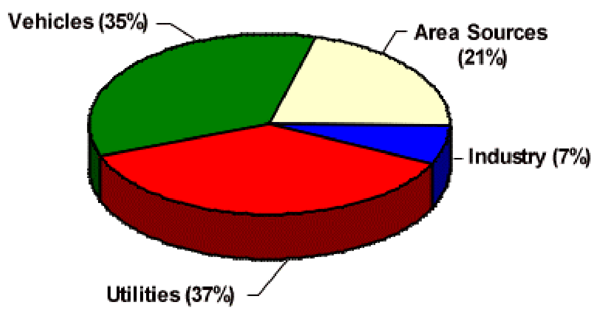


B. Signatory States

The Signatory States for the Chesapeake Bay Agreement include Virginia, Pennsylvania and Maryland and the District of Columbia. Based on modeling conducted by the National Oceanic and Atmospheric Administration (NOAA) in 2001, information is available that predicts the relative contribution of nitrate deposition from sources in the signatory states.

The Model

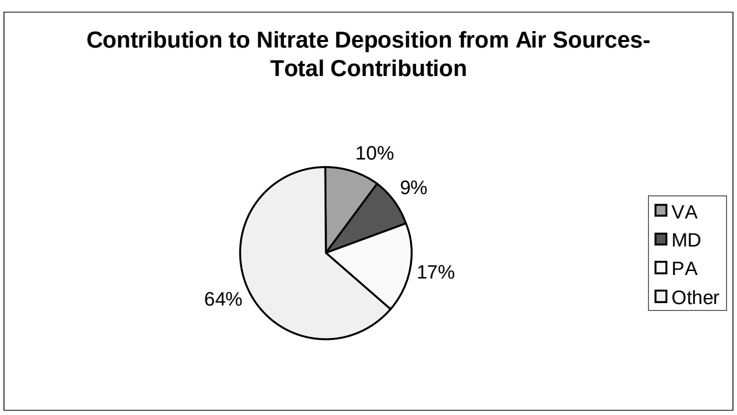
Robin Dennis of NOAA used the extended version of the Regional Acid Deposition Model (Extended RADM) to predict relative changes in nitrate deposition in both wet and dry forms under various control scenarios. A 1990 data baseline was used. These data were the latest available, but may not accurately represent the current baseline because of the age of the data. The baseline case used for the model used a total of 2,001,000 tons /year of NOx for the signatory states. This compares with 3,157,000 tons/yr for all six basin states. The baseline emissions included estimated emissions from vehicles, industry, utilities, and area stationary and nonroad sources.



Distribution of Point and Non-Point NOx Sources in the Three Signatory States

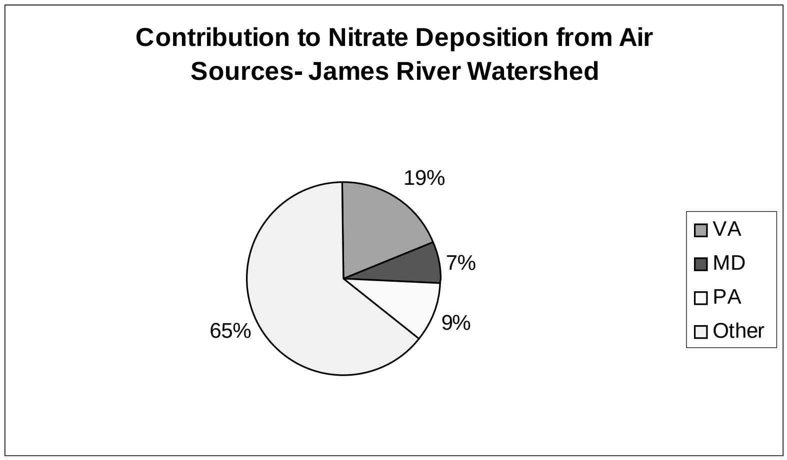
The Results for Signatory States

The model run, which used several representative meteorological conditions, estimated the relative nitrate contributions by state to different tributaries and the signatory state's contribution overall. All the sources modeled in the airshed, accounted for 76% of the nitrate deposition. Of the 76% total, roughly one-third or 36.28 % was contributed by nitrogen emissions from the signatory states.



Tributaries: James River

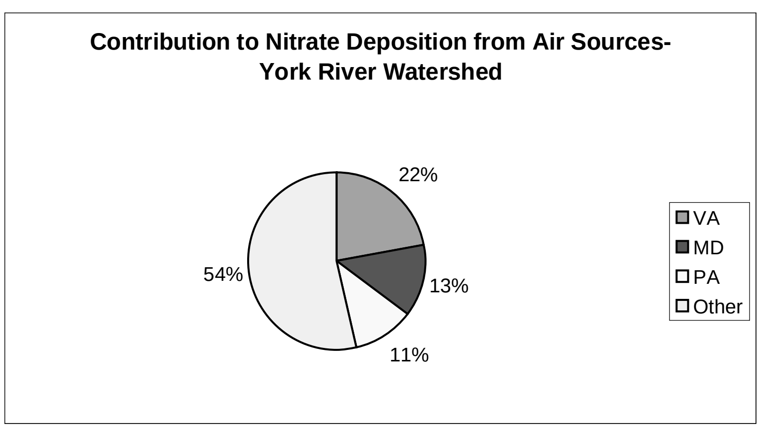
The model also estimated the nitrate deposition contributions of the air emissions sources from the airshed into various tributaries. The air emissions sources from the signatory states account for 35.74% of the total wet and dry nitrate deposition into the James River.



Of the 19% contributed by Virginia sources to nitrate deposition to the James River watershed, nearly half, 8.76% is from mobile sources in the State.

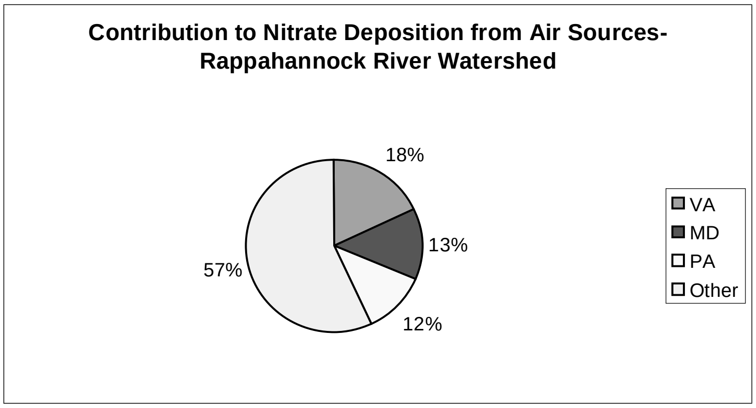
Tributaries: York River

The air sources included in the model account for a larger percentage of the nitrate deposition into the York River; i.e., 46.3% of the deposition can be attributed to air emissions from the signatory states. Mobile sources in Virginia account for 10.03% or nearly half of the deposition from Virginia air sources.



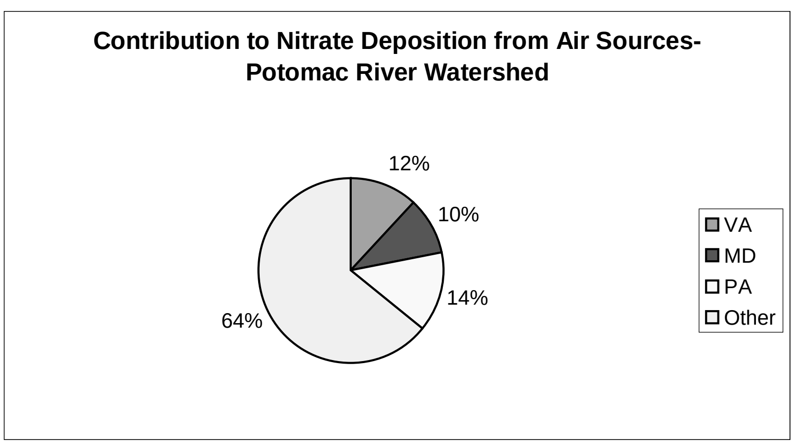
Tributaries: Rappahannock River

The results for the Rappahannock are similar to those for the other tributaries in the watershed. Air sources for the signatory states contributed 43.2% of the **nitrate** deposition to the Rappahannock. Virginia mobile sources contributed 9% or half of the total air source deposition from the State.



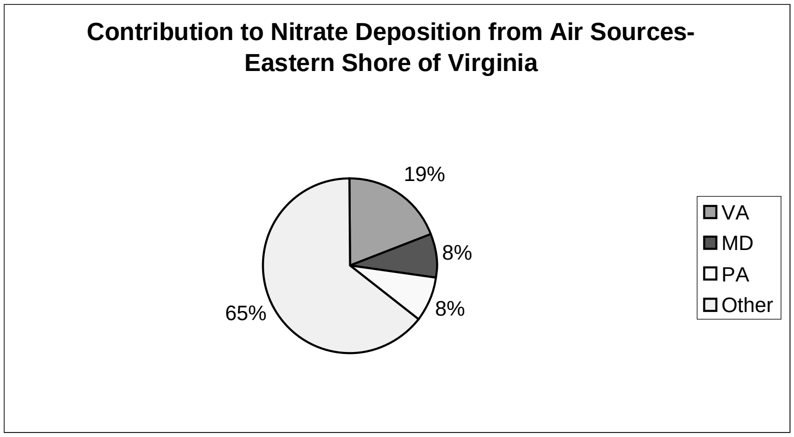
Tributaries: Potomac River

The air emissions from the signatory states contribute 35.82% of the nitrate deposition to the Potomac River watershed. In the case of the Potomac, Pennsylvania sources have the largest contribution to the watershed. However, like the other watersheds discussed above, mobile sources contribute 5.9%, nearly half of the deposition attributed to air sources, 11.9%, from Virginia.



Tributaries: Eastern Shore-VA

Based on the modeling by NOAA, air emissions from the signatory states account for 35.5 % of the nitrate deposition to the Eastern Shore of Virginia. Mobile sources account for around 45% of the deposition from Virginia air sources to the Eastern Shore of Virginia.



C. Virginia's Contribution by Source Type

ExRADM modeling performed by the Atmospheric Modeling Division of EPA/NOAA, using the extended version of the Regional Acid Deposition Model (Extended-RADM) located in Research Triangle Park, NC also provided information about Virginia's contribution from air source to nitrate deposition. NO_x emissions from the 1990 inventory provided the input for these studies. These emissions were available for stationary area sources (e.g., residential, commercial, etc.), non-road area sources (e.g., construction equipment, lawn mowers, etc.), electric generating units (i.e., power plants), non-electric generating units (i.e., industrial point sources), and mobile sources.

Virginia's 1990 baseline NO_x emissions from all of these sources totaled 564,357 tons per year. An estimate of the Virginia contribution to nitrate deposition to the entire Chesapeake Bay watershed, as well as to each of the major tributary watersheds, is summarized in the following table. Overall, Virginia contributes about 10% of the total predicted nitrate deposition, second only to Pennsylvania among the basin states. This percent contribution to deposition is highest in Virginia's Eastern Shore, the James, York and Rappahannock basins. From the standpoint of mass of nitrogen deposited (lbs. N/yr.), however, the James, Potomac, Susquehanna and York are the primary recipients.

NOAA has updated the estimates of historical deposition, using the Extended RADM and the 1996 NO_x emissions inventory. These estimates indicate that nitrate deposition is slightly higher with the increase attributable mostly to mobile sources. A new model (CMAQ/Models-3) will be available for use in 2003. NOAA will apply this new model to evaluate nitrate deposition using the 1999 emissions inventory.

In addition to the 1990 baseline emissions scenario, RADM was used to estimate the change in deposition resulting from four different NO_x control scenarios. Next steps include a look at how the percent contributions from the six basin states change with application of the first two of these control scenarios that are based on regulatory requirements already promulgated

Tributary	% Contribution				MM lbs/yr			
	Mobile	**Utilities**	**All Other**	**Total**	**Mobile**	**Utilities**	**All Other**	**Total**
James	8.76	2.94	7.48	19.18	3.87	1.30	3.31	8.48
York	10.03	3.69	8.53	22.25	1.28	0.47	1.09	2.85
Rappahannock	8.99	2.78	6.27	18.04	1.03	0.32	0.72	2.08
Potomac	5.88	1.52	4.50	11.90	3.48	0.90	2.67	7.05
Patuxent	6.39	2.20	4.84	13.43	0.24	0.08	0.18	0.51
CB-WS-MD	5.18	1.77	4.25	11.20	0.34	0.12	0.28	0.75
Susquehanna	1.70	0.49	1.57	3.76	2.36	0.68	2.18	5.22
CB-ES-MD	4.98	1.94	4.31	11.23	0.66	0.26	0.57	1.48
CB-ES-VA	8.70	3.18	7.41	19.29	0.12	0.04	0.10	0.26
Total Watershed	4.84	1.51	4.00	10.35	13.39	4.17	11.10	28.66

Notes:

1. CB-WS-MD denotes Chesapeake Bay, Western Shore, and Maryland.
2. CB-ES-MD/VA denotes Chesapeake Bay, Eastern Shore, and Maryland/Virginia.
3. Contributions in MM lbs per year were calculated using the % contributions, the Total Nitrogen Deposited to the entire watershed (except for the Eastern Shore of Delaware) as reported by R. Dennis, NOAA/EPA of 388.82 MM lbs per year and a factor of 75% to arrive at the Nitrate Deposited (291.62 MM lbs per year).

D. Other Contributing Sources

Modeling of the Chesapeake Bay sponsored by the Chesapeake Bay Program[1] has estimated that 32% of the total nitrogen loading in the Bay comes from atmospheric deposition. The majority of the contribution from atmospheric deposition is attributed to nitrogen emitted to the air that is deposited on the ground and later washed into the Bay, rather than the nitrogen that is deposited directly onto surface waters within the Bay. Although the Chesapeake Bay watershed includes only six states, model results of the transport and dispersion of emissions to the air indicate atmospheric emissions from as many as 36 states end up in the Chesapeake Bay. In fact, model results attribute less than half of the nitrogen loading associated with atmospheric deposition to emissions that originate within the six states that are in the Chesapeake Bay watershed.

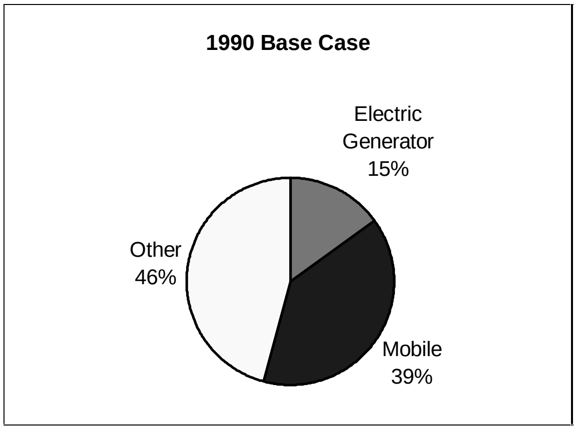
Based on modeling using 1990 emissions data, the Chesapeake Bay Program determined that approximately 10.35% of the modeled nitrogen deposition could be attributed to emissions originating from sources in Virginia. The individual state contributions were further divided into three groups: on-road vehicles (or mobile sources), electricity generators and miscellaneous sources (e.g. non-road vehicles, area sources and residential, commercial and industrial boilers). Approximately 46.7% of the contribution from sources in Virginia were attributed to on-road vehicles; electricity generator emissions were associated with 14.6%; and the remaining 38.7% came from the miscellaneous category.

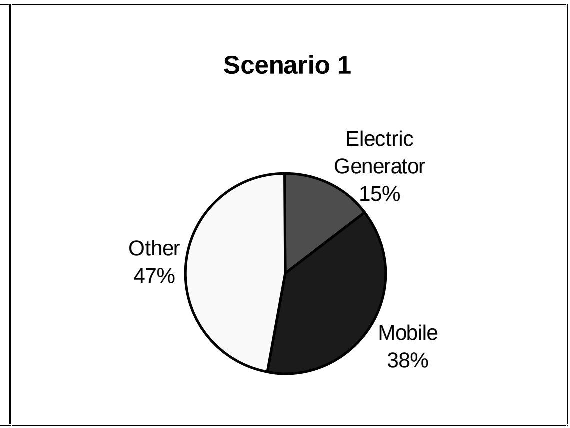
1. Scenarios for NOx Emission Reductions

Modeling has been conducted for four future scenarios using a 1990 baseline. The first two assume the implementation of regulatory programs that are already in place, but were not in effect in 1990. The last two consider possible more stringent future emission limits for electricity generation, other industry and on-road vehicles. As shown in the table below, the incorporation of new limits imposed by the regulatory programs that are already in place results in a 41% reduction in NOx emissions from sources in Virginia by 2020 (Scenario 2).

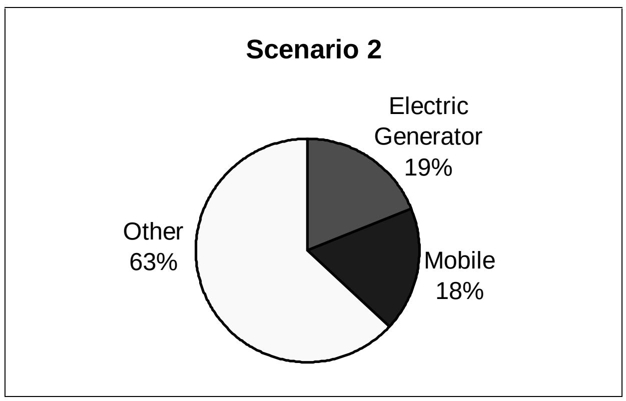
Scenario	Electric Generators		Mobile Sources		Miscellaneous		Total	
	Tons/yr	% reduction	Tons/yr	% reduction	Tons/yr	% reduction	Tons/yr	% reduction
Base	84,915	NA	220,398	NA	259,044	NA	564,357	NA
1	67,011	21.08	174,178	20.97	215,059	16.98	456,249	19.16
2	62,471	26.43	59,949	72.80	208,588	19.48	331,008	41.35
3	28,162	66.84	59,949	72.80	208,588	19.48	296,699	47.43
4	28,162	66.84	33,445	84.83	177,895	31.33	239,502	57.56

Scenario 1 projects the 1990 inventory to 2010 assuming the NOx emission reductions from (1) power generation required by the Acid Rain Program and the NOx SIP Call, (2) light duty vehicles required by the Tier II tailpipe standards and (3) residential and industrial sources as required by various other programs. NOx emissions from coal-fired electricity generators were reduced in two phases under the Acid Rain Program beginning in 1995 and 2000. These acid rain affected units and all other power generators will be required to make additional reductions during the summer months beginning in May 2004 as the recently approved NOx Trading Program is implemented in Virginia in response to the NOx SIP Call. Tier II emission limits for on-road vehicles will be phased in beginning with the 2004 model year.





Scenario 2 projects the inventory to 2020 and assumes all of the reductions that were assumed in Scenario 1 and the reduction in emissions from heavy duty diesel vehicles expected by 2020.



Scenario 3 assumes the power generation sector applies the seasonal NOx reductions required by the NOx SIP Call year-round and reduces the average emission rate from 0.15 lb NOx/mmBtu to 0.10 lb NOx/mmBtu. These requirements are not part of current regulatory requirements, although legislation is currently under debate that includes similar mandates

Scenario 4 assumes that industrial emissions are cut almost in half and the use of super ultra-low emissions vehicles in light duty vehicles. These requirements are not part of current regulatory requirements or proposed legislation. Without completing the modeling using a more recent baseline; however, we can not assume that the contribution from sources within Virginia to nitrogen loads in the Chesapeake Bay will be reduced by a similar amount because the of the complex relationship between emissions and nitrogen loading. For example, the 1990 inventory assumes that emissions from the mobile source category made up 39% of the total emissions from Virginia, but were estimated to have contributed almost 47% of the nitrogen loading to the Bay associated with emissions to the air from sources in Virginia. Once available, the model results can be used not only to determine if additional measures need to be taken, but also to identify from which sector of the inventory reductions would be most effective in reducing nitrogen loading to the Bay.

2. Future Programs

Reductions that have not yet been considered in the modeling may be expected based on an agreement signed in June 2002 between the Maryland Department of Natural Resources, the National Marine Manufacturers Association, the Marine Retailers of America, and the Marine Trade Association of Maryland. In the agreement, the signers pledged to promote the use of low polluting, electronically fuel injected two-stroke and four-stroke outboard engines by boaters throughout the state. These engines reduce emissions to both the air and water. Additionally, the EPA has recently proposed a rule that would require reductions in NOx emissions from large ocean-going vessels built after 2004. The model inventory needs to be further refined to incorporate reductions that can be expected from marine traffic. In addition, potential legislation to further reduce emissions from electric generation will further reduce NOx emissions from this source.

In addition to updating and refining emission inventories for combustion sources, the Chesapeake Bay Program is working to better understand the significance of ammonia emissions to nitrogen loading in the Chesapeake Bay. The *3rd Report to Congress on the Deposition of Air Pollutants to the Great Waters*[2] suggests that ammonia and ammonium, primarily released from crop and animal farming operations, contributes 20 to 40 percent of total atmospheric deposition nitrogen to the Chesapeake Bay. Emissions from this type of source needs to be more accurately quantified so that their contribution to total nitrogen loading in the Bay can be more realistically reflected in the model results.

E. Conclusion

There is a considerable body of modeling and analysis studying nitrogen deposition for the Chesapeake Bay. More studies are underway by the EPA NOAA Bay Program to assist in the complete characterization. Regulatory programs, such as the NOx SIP Call, tailpipe emission controls, residential activities, will reduce Nitrogen Oxide deposition to the Bay airshed by over 41%.

III. Recommendations

- Track the modeling efforts of EPA/NOAA. Assign a specific DEQ staff person the responsibility for participation in the modeling programs, tracking progress of the multi-EPA/NOAA, Maryland and Virginia programs and providing status reports to the Air Pollution Control Board.
- The DEQ should encourage EPA/NOAA to routinely reassess the effects of reductions in atmospheric deposition as control programs are put into effect and provide routine analysis and updates to the Board.

IV. Attachments

1. Location Map of the NADP Monitoring Sites within the Chesapeake Bay Region.
2. Report from the Airsheds and Watersheds III Shared Resources Workshop, "The Significance of Ammonia to Coastal and Estuarine Areas", November 15-16, 2000. NOAA Chesapeake Bay Office.
3. "Atmospheric Deposition Monitoring," available from the Chesapeake Bay Program Office at http://www.chesapeakebay.net/atmos.htm, May, 17, 2001.
4. Analysis of the Principal Nitrogen Airsheds for the Chesapeake Bay, developed by Robin Dennis of the Atmospheric Sciences Modeling Division: ARL, NOAA and NERL USEPA.
5. "Ammonia Exchange between the Atmosphere and the Surface Waters at Two Locations in the Chesapeake Bay" by Larsen, et. al. "Environmental Science & Technology, 2001, 35, 4731-4738.
6. "Atmospheric Nitrogen Deposition to Estuaries in the Mid-Atlantic and Northeastern United States" by Castro and Driscoll. "Environmental Science & Technology, 2002, 36, 3242-3249.
7. "Bay Program Narrows Range for Nutrient Reductions" by Blankenship. Bay Journal from the Alliance for the Chesapeake Bay, May 2002.
8. Presentation/working Papers from Maggie Kerchner, NOAA/ARL, to the SAB Subcommittee on April 12, 2002.